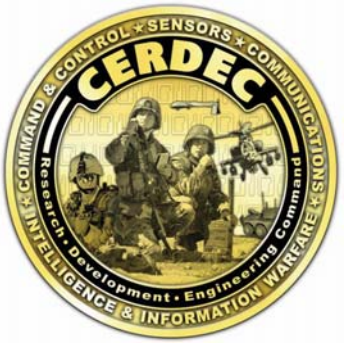
Power Generation and Alternative Energy Branch
US Army RDECOM CERDEC CP&ID Power Division
Aberdeen Proving Ground, MD



PGAE - CR – 12 – 10

Microscale Waste Heat Driven Cooling System

Michael Garrabrant, et al, Stone Mountain Technologies Inc

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14. ABSTRACT
A presentation to the Inter-Agency Power Group Mechanical Working Group Meeting 2012 about the ammonia-water absorption chiller technology demonstrator developed by Stone Mountain Technologies Inc under an American Recovery and Reinvesment Act contract with the US Army Communications-Electronics Research Development and Engineering Center is provided.

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Microscale Waste Heat Driven Cooling System

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Dr. Srinivas Garimella
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May 2, 2012

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Smaller Lighter Co-Generation & Absorption Environmental Control Technologies

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Patricia Davis, Contracting Officer

William Campbell, Contracting Officers Representative

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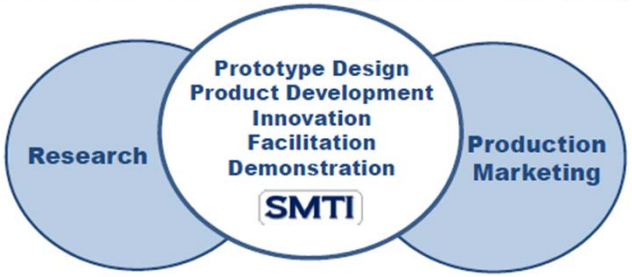
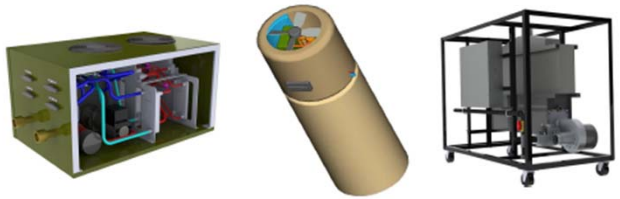
Stone Mountain Technologies, Inc.

Research • Product Development • Consulting



- Waste Heat Driven Chillers
  Engines, Turbines & Fuel Cells
- Residential Solar Cooling
- Gas Heat Pump Water Heaters
- Heat Pump Crop Dryers
- High Performance Process Heating
- Modulating Combustion

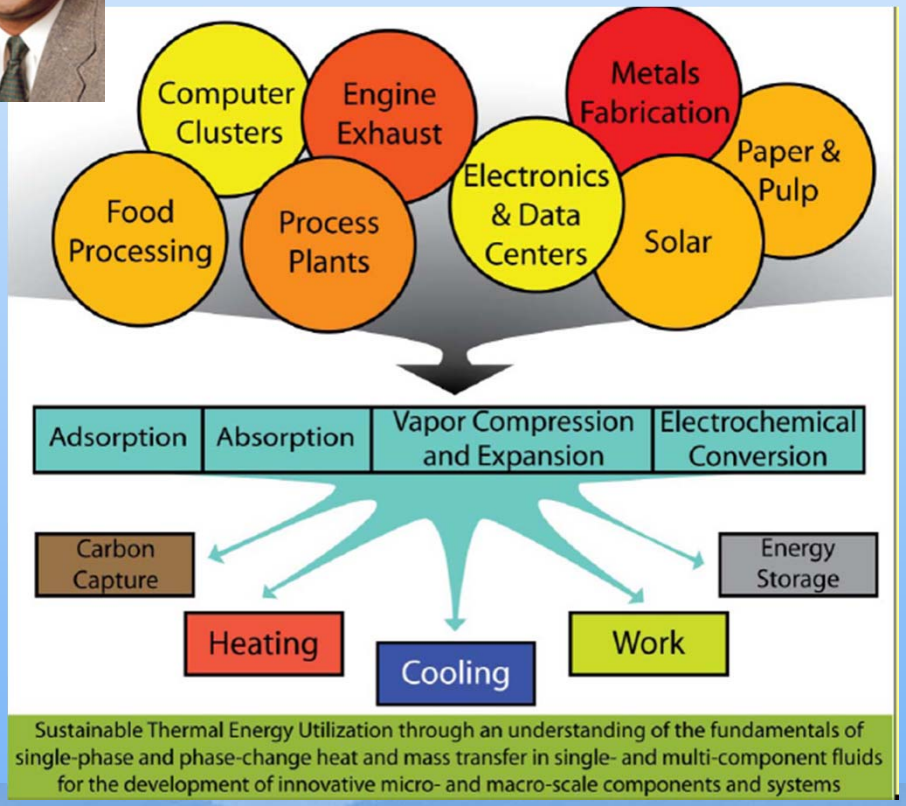


"Sustainable Products for a Sustainable Future"

Dr. Srinivas Garimella

Georgia Tech

Sustainable Thermal Systems Lab



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Microscale Waste Heat Driven Cooling System

Objective

Medium Sets

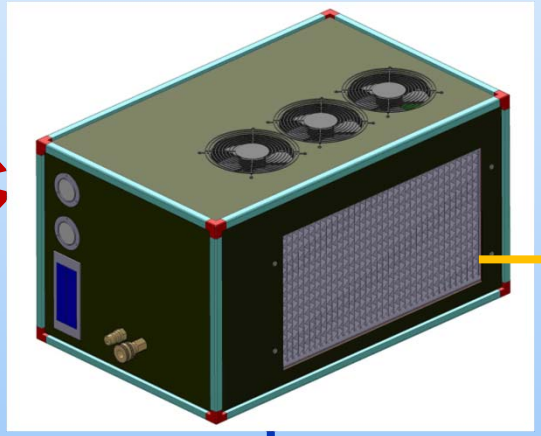
- 5kW, 10kW, 15kW, 30kW, and 60kW, Skid Mounted, Diesel Fueled Tactical Quiet Generator, 60Hz and 400Hz
- AMMPS – Advanced Medium Mobile Power Sources

Power Unit/Power Plant (PU/PP)

- Trailer Mounted Tactical Quiet Generators in the 3kW, 5kW, 10kW, 15kW, 30kW, 60kW, 100kW, and 200kW Power Ratings.
- 20 Different Models That Use 4 Different But Standardized TACOM Trailer Models

Waste Heat

Microscale Heat Pump



Reject Heat to Ambient

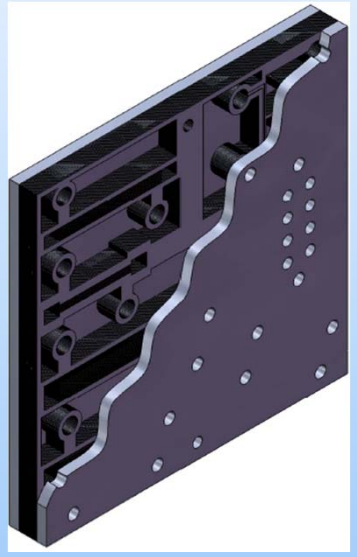
Direct Air-Cooled

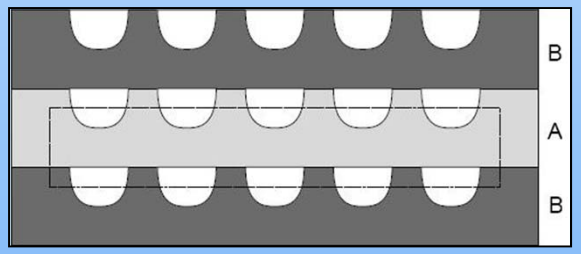
1 – 20 kW Cooling

Develop a diesel engine waste heat driven ammonia-water absorption environmental control unit (ECU) using micro-scale heat exchanger technology.

Microscale Waste Heat Driven Cooling System

History & Rationale





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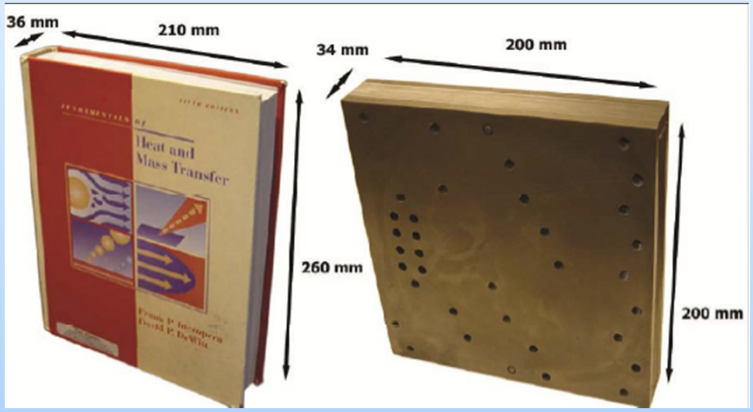


- **Can it be scaled to larger capacities?**
- **Can it be manufactured using low cost processes?**
- **Is counter-flow heat and mass transfer possible in microscale geometries?**

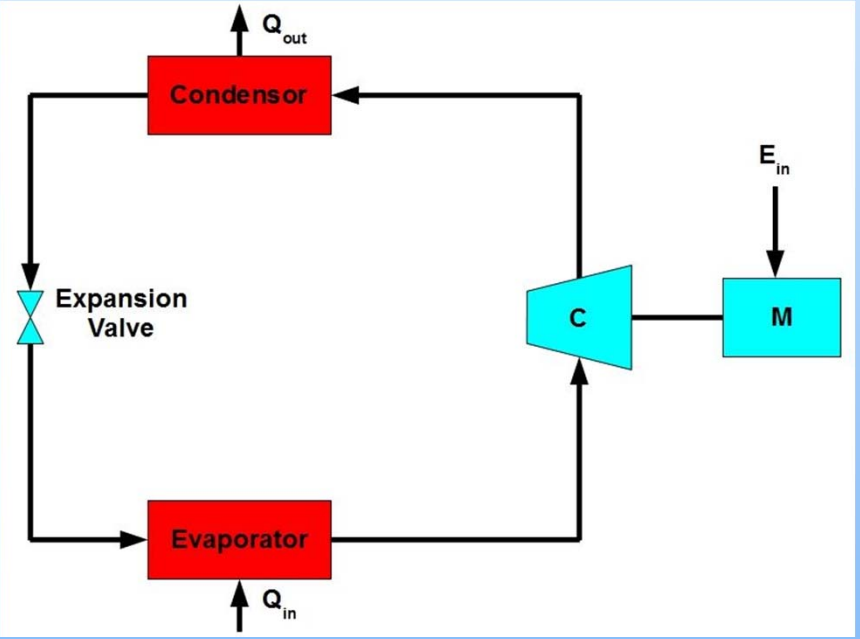
Microscale Waste Heat Driven Cooling System

Major Project Tasks

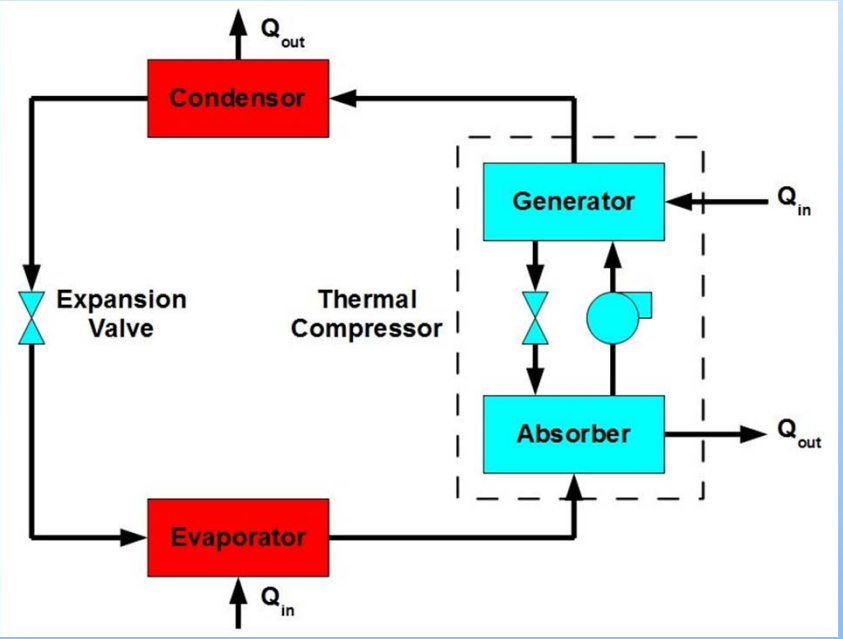
- Optimize Absorption Cycle For Application
- Microscale Heat Exchanger Design for Absorption Systems
- Low-Cost Microscale Heat Exchanger Manufacturing Method
- Compact Solution Pump Development
- Breadboard Testing
- 2kW Packaged Prototype Demonstration Unit

Microscale Waste Heat Driven Cooling System
Cycle Optimization

Vapor Compression Cycle



Absorption Cycle



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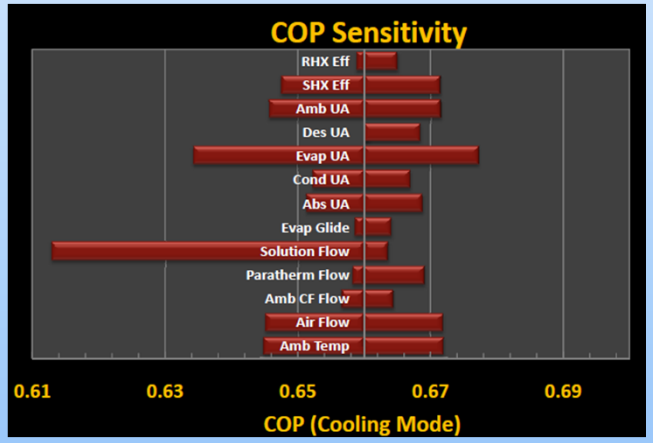
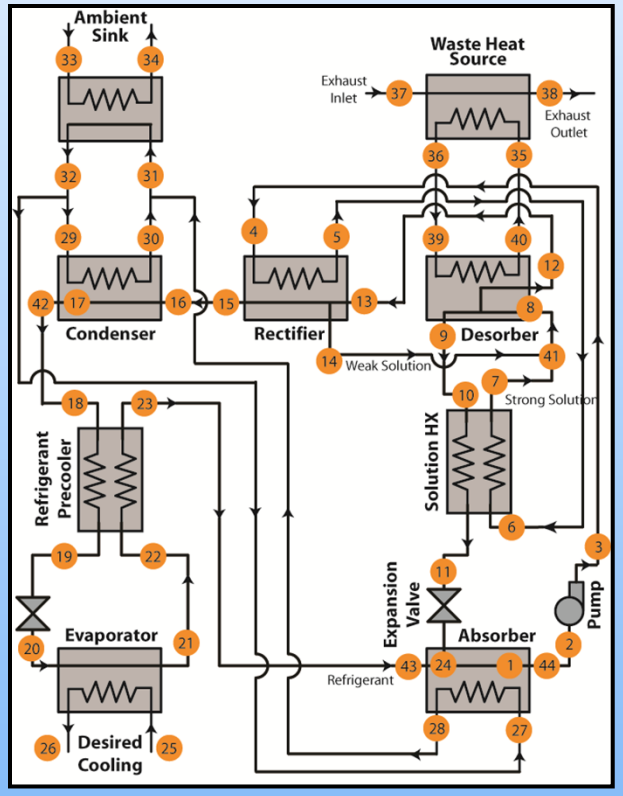
Microscale Waste Heat Driven Cooling System

Cycle Optimization





Component	UA (kW/K)	Duty (kW)
Rectifier	0.014	0.45
Solution HX	0.100	1.49
Desorber	0.079	3.11
Condenser	0.350	2.02
Precooler	0.039	0.21
Evaporator	0.502	2.09
Absorber	0.300	3.19
Ambient HX	2.400	5.21
Exhaust HX	0.032	3.11
COP	0.67	

95°F Ambient
45/55°F Chilled Water

Optimized Waste Heat Driven Absorption Cooling Cycle

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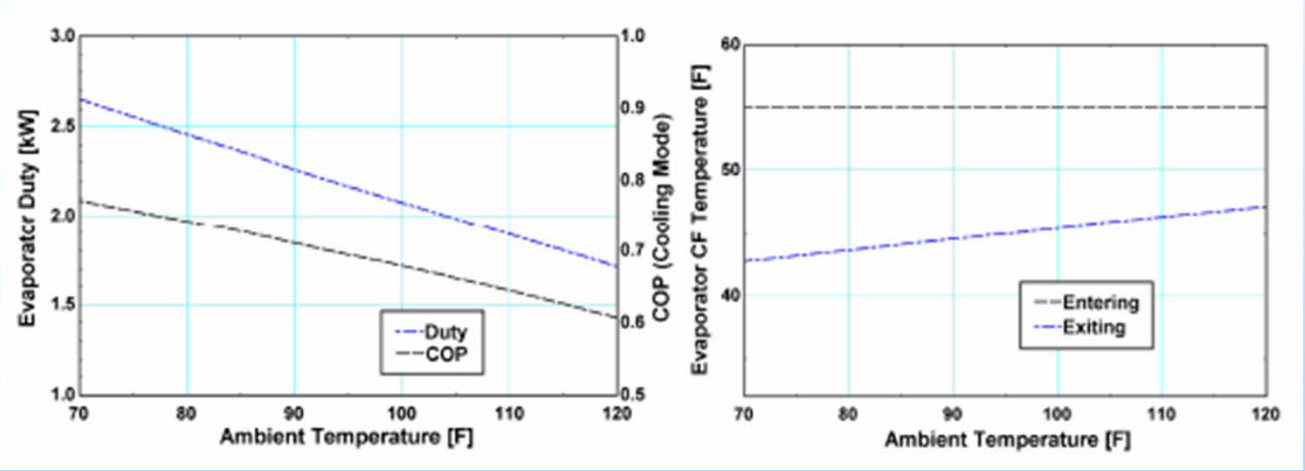
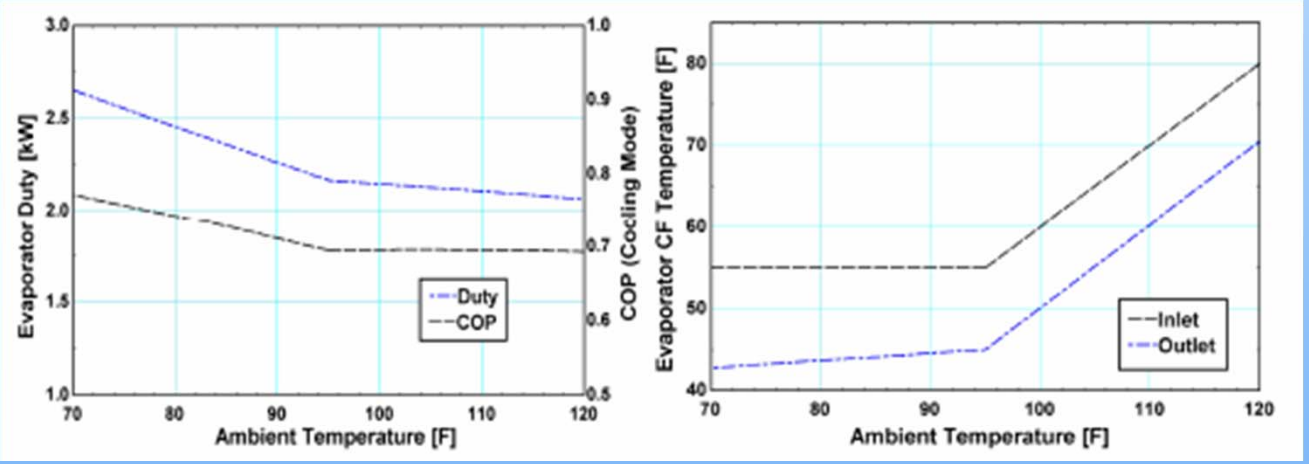
Microscale Waste Heat Driven Cooling System

Cycle Optimization





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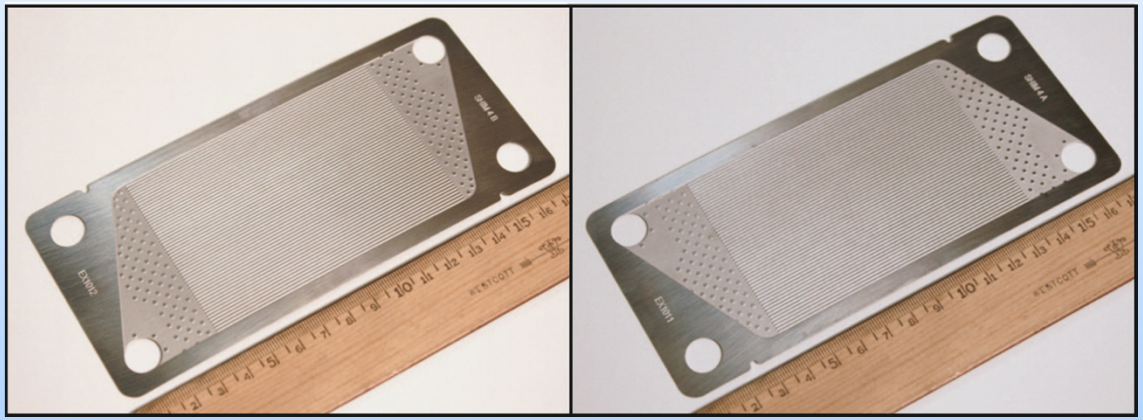
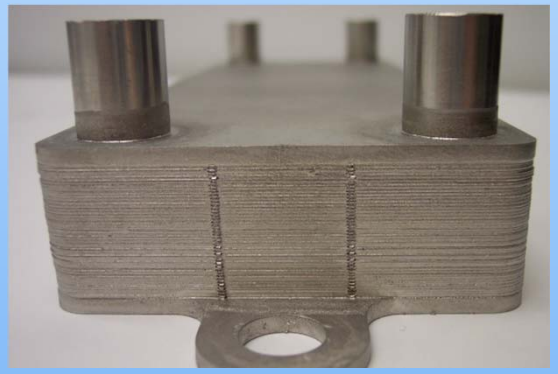
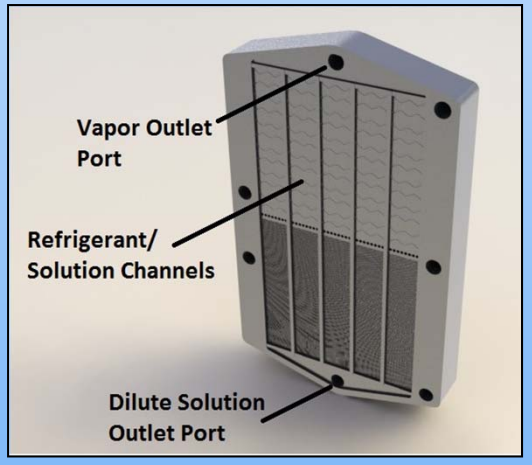
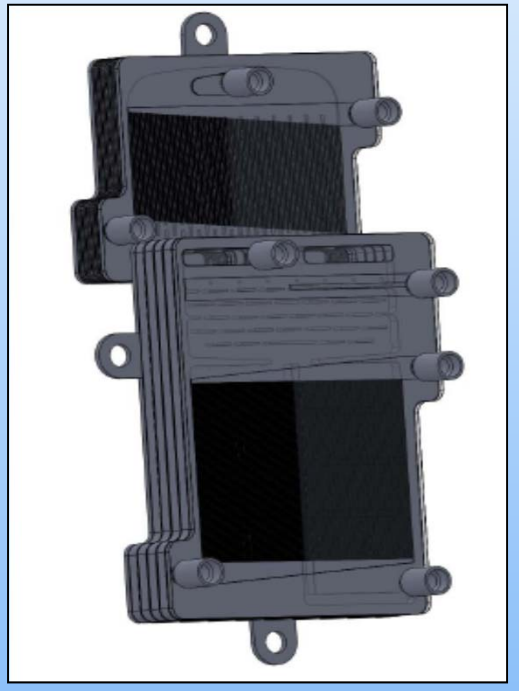
Microscale Waste Heat Driven Cooling System

Microscale Heat Exchanger Design







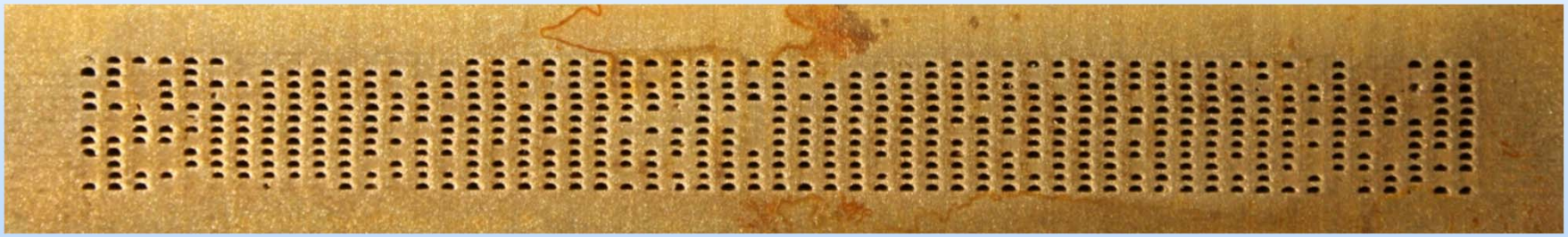


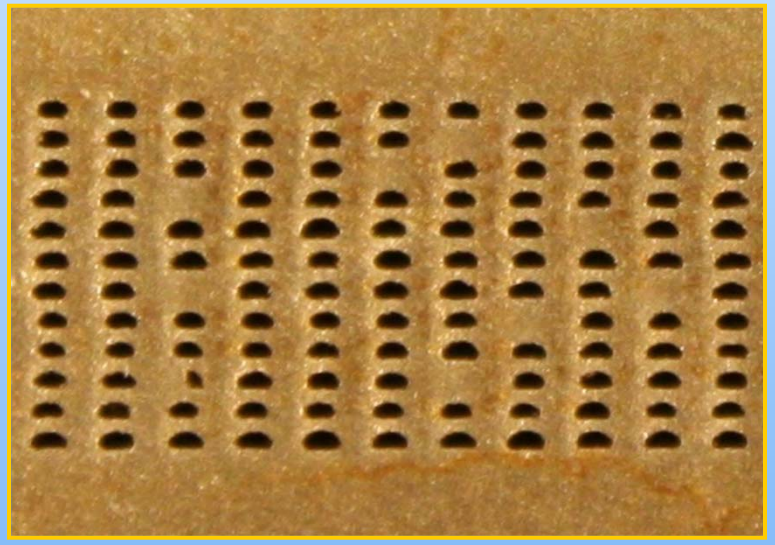
Microscale Waste Heat Driven Cooling System
Microscale Heat Exchanger Manufacturing Development

- **Microscale Shim Production**
  - Chemical "Photo" Etching Used for Proof-of-Concept & Shims for this project
  - Proven process can achieve dimensions and tolerances
  - Dedicated production line can hit target production costs
- **Heat Exchanger Bonding**
  - **Diffusion Bonding Used for Proof-of-Concept**
    - Slow, expensive, one-at-a-time process
  - **Nickel Brazing Lower Cost Method**
    - Can braze 50 – 200 in single furnace run (vs 1 – 2 using Diffusion Bonding)
    - Potential Use of Continuous Belt-Type Furnace
  - **Nickel Brazing Technical Issues**
    - Micro channel size reduction and/or blockage
    - Amount of Alloy: Pressure Tightness vs. Channel Blockage
    - Alloy Application: Spray, Plating, Foil
    - Furnace Temperature and Heat/Cool Rates

Microscale Waste Heat Driven Cooling System

Microscale Heat Exchanger Manufacturing Development





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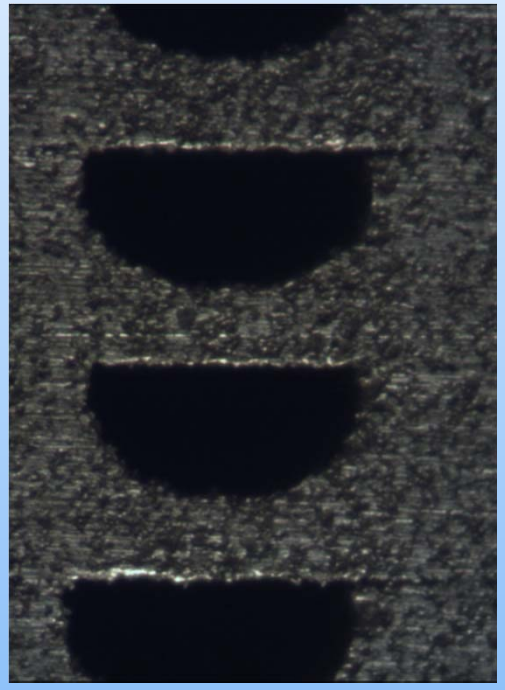
Microscale Waste Heat Driven Cooling System

Microscale Heat Exchanger Manufacturing Development

- Brazing at 100% Success
- Minimal Full Channel Blockage
- Hydraulic Diameter Reduction
  - 5 – 20%
- Limiting HX Performance
  - Distribution Channel-Channel



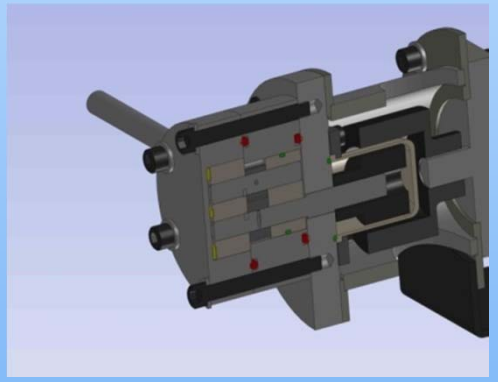
Microscale Waste Heat Driven Cooling System
Solution Pump Development

Unique Design Requirements

- Low Flow Rate/ High Head (300+ psig)
- Solution Near Saturation Point
- Ability to Pump Partial Vapor
- Compact and Low Cost
- Hermetically Sealed
- Long Service Life
- No Normal Lubricants

Historically Used Technology

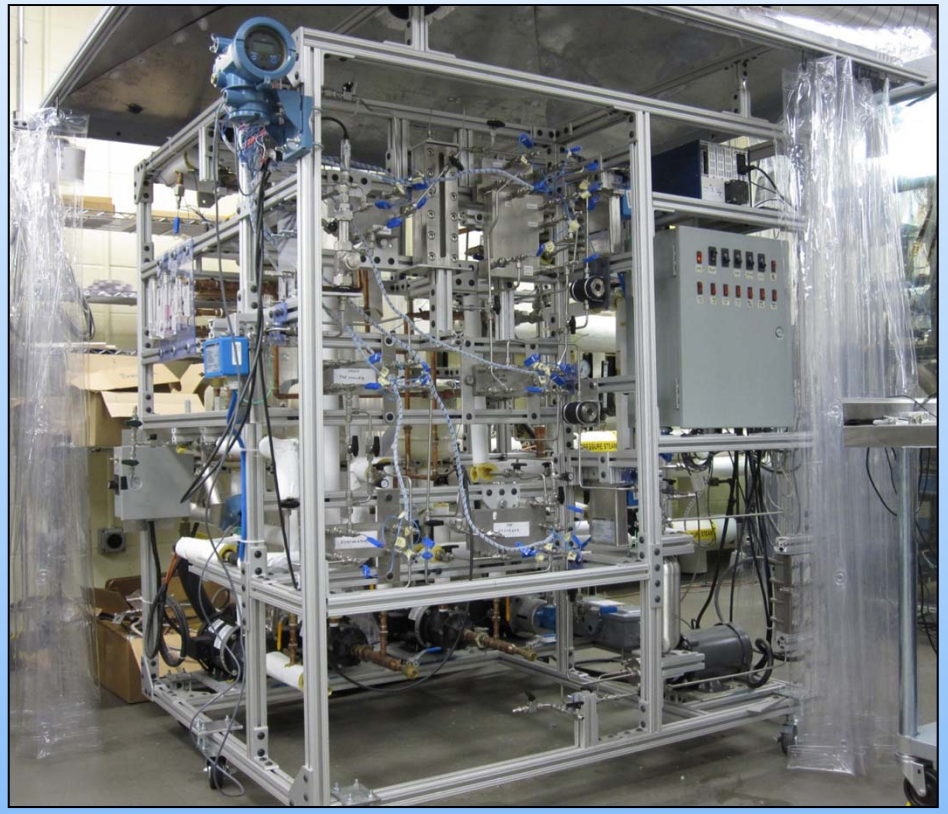
- Hydraulically driven diaphragm
  - piston or vane oil pump
- Complex, expensive, large, heavy



Microscale Waste Heat Driven Cooling System

Breadboard Testing – Georgia Tech Sustainable Thermal Systems Laboratory

- Independent control of each hydronic loop
  - Condenser
  - Evaporator
  - Absorber
- Heat Transfer Fluid - Desorber
  - Steam heating
- Mass Flow, Thermocouple and Pressure Transducers at each state point



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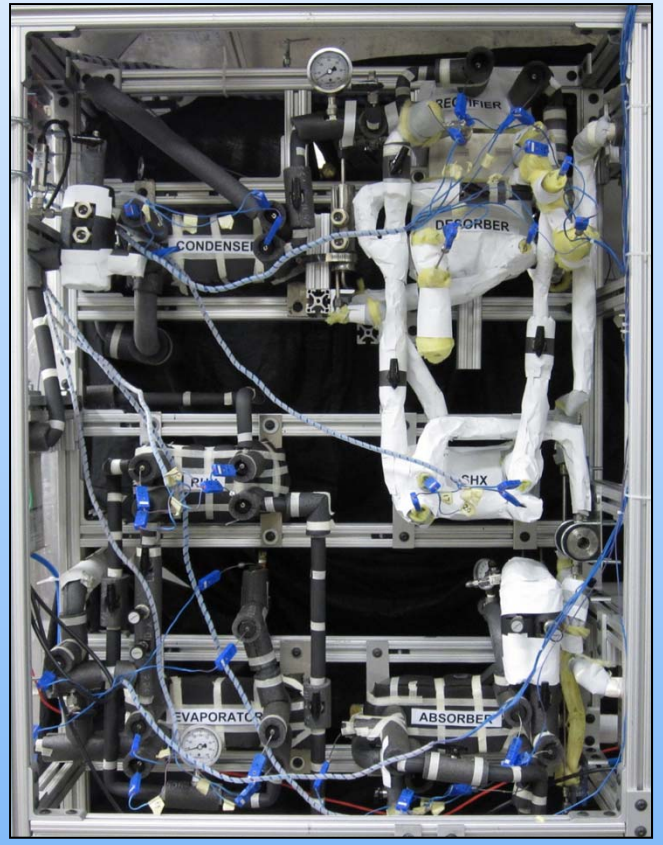
Microscale Waste Heat Driven Cooling System

Breadboard Testing – Georgia Tech Sustainable Thermal Systems Laboratory

- Two Desorber-Rectifier Designs
- Two Absorber Revisions
- 1.9 kW steady state cooling
- 0.60 – 0.64 COP, baseline conditions

Desorber-Rectifier Rev 1:	100%
Desorber-Rectifier Rev 2:	95%
Condenser:	100%
RHX & SHX:	80-90%
Evaporator:	80%
Absorber A:	50%
Absorber B:	65%



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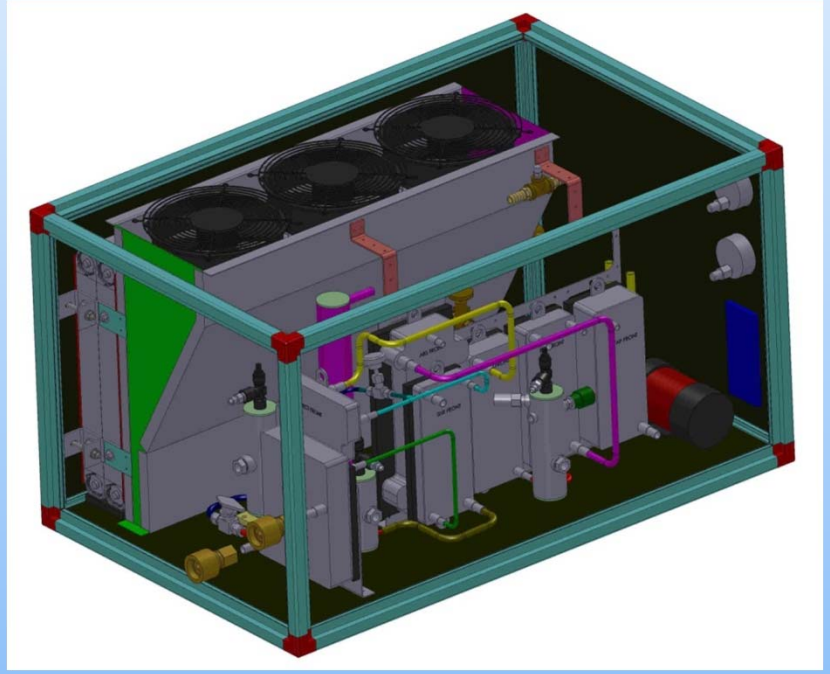
Microscale Waste Heat Driven Cooling System
Packaged Prototype

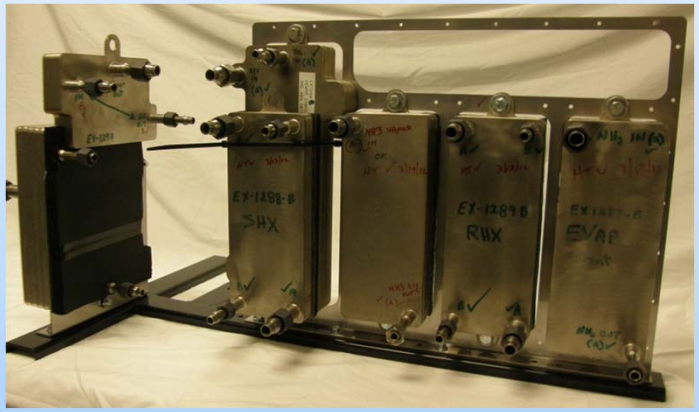
- **Designed/Sized 2nd Gen HX's**
  - Based on Lessons Learned
- **"Off-the-Shelf" Ambient Coil**
  - Variable Speed Fans
- **Packaged Unit Layout**
- **PLC Control System**
  - Development of Control Algorithm
- **Electronic Expansion Valve**
  - Optimum Performance vs Ambient

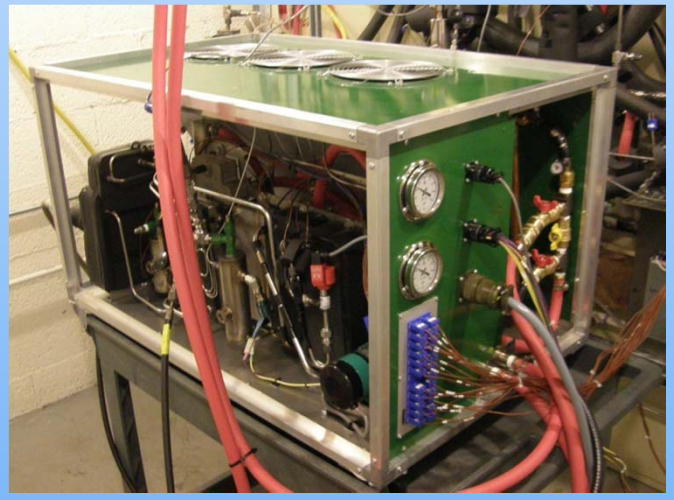


Approximate Size: 20 x 20 x 36" (ambient coil constrained)

Microscale Waste Heat Driven Cooling System

Packaged Prototype





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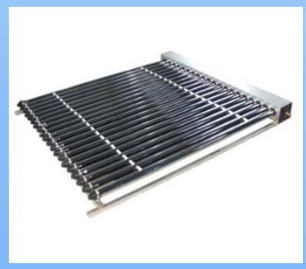
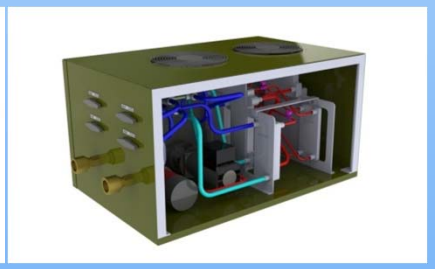
Microscale Waste Heat Driven Cooling System

Packaged Prototype

Air-Cooled Ammonia-Water Absorption
Commercialization Opportunities

- **Military/Commercial/Industrial CCHP**
  - Gas-Engine and Micro-Turbine Exhaust Driven Refrigeration
    - Food Processing & Restaurants
  - SOFC Waste Heat Driven Space Cooling and Refrigeration
- **Residential and Light Commercial Solar Driven**
  - Space Cooling or Refrigeration
  - Domestic Hot Water
- **Residential and Commercial Domestic Hot Water Heating**
  - Gas-Fired COP > 1.5
- **Micro CCHP**
  - Residential Sized Gas Engine and Fuel Cell





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Thank You!